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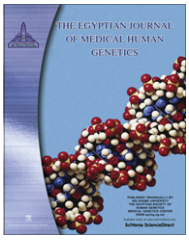

REVIEW

Role of Gal and GalNAc containing glycans in various physiological processes

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Sequence and anomeric linkages;
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Abstract Glycoconjugates are involved in the vital physiological functions including blood group determination, cancer recognition, protein stabilization, sperm-egg adhesion and pathogenic interaction in body. These diverse biological functions of glycoconjugates are regulated by complex oligosaccharide structures linked with proteins and lipids in macromolecular assemblies. The diversity in oligosaccharide chains attached with lipids and proteins is specifically linked with the conformational behavior of sugar residues giving rise to unique carbohydrate structures with wide range of sequence and anomeric linkage. This is a challenging task to explore the relationship between biological processes and stereochemical behavior of sugar residues. Current review article focuses the specific stereochemical involvement (anomery and linkages) of Gal and its derivative GalNAc in wide range of cellular activities. These sugar residues exhibit different physiological functions at the terminal and subterminal position in glycans.

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Contents

1. Introduction

Complex biomolecular assemblies carrying diverse glycan chains are involved in wide range of pathological and physiological activities. Diversity of glycan chains, linked to lipids and proteins is due to isomeric and conformational modifications of various sugar residues, giving rise to unique carbohydrate structures with wide range of anomeric linkages. This unique and significant structural diversity of naturally occurring oligosaccharide structures make them best recognition markers for countless physiological activities. Today the scientists (biochemists, immunologists, molecular biologists, microbiologists, pathologists and pharmacologists are doing tremendous effort to explore the relationship of sugars with their glycobiology.

Glycoproteins and glycolipids are the major constituents of biomembranes, regulating the wide range of cellular functions including cellular differentiation, interaction and communication. In nature, approximately 90% of the glycosylated proteins are *N*-linked having oligosaccharide chains attached with Asn of parent protein structure. While in mucins (*O*-linked glycoproteins, oligosaccharide chains are attached with serine (Ser)/threonine(Thr) through GalNAc residue [1–7].

Sugar residues like *D*-galactose (Gal), *N*-Acetyl-*D*-galactosamine (GalNAc), *D*-glucose (Glc), *N*-Acetyl-*D*-glucosamine (GlcNAc), *N*-acetyl neuraminic acid (NeuAc), fucose (Fuc) and mannose (Man) are widely carried by glycolipids (GM1, GD1a, GD1b, GT1b, GM2, GM3, GD2, GD3 and GT1c gangliosides), glycoproteins, glycosylphosphatidylinositol-anchored (GPI-anchors) proteins and many other glycoconjugates [8–13]. Our main focus in this article is to relate the particular structural features of Gal and GalNAc with their cellular physiology.

The C-4 axial positioned hydroxyl group of Gal distinguishes it from glucose sugar (having equatorial OH group). GalNAc, which is the derivative of Gal, contains *N*-acetyl amine at C-2 position instead of OH group. This NHAc group discriminates the GalNAc from the Gal sugar due to its charge density and stereoelectronic configuration. The changed physiological behavior of GalNAc can be examined by the simple example of ABO blood group system. The recognition of blood group A is specifically linked with terminal GalNAc (α1-3) in lacto series of oligosaccharide chain while the blood group B variant is associated with Gal sugar terminally linked with the oligosaccharide chain. So, the nature of sugar residue is vitally important in cellular physiology [14,15].

The modifications on Gal and GalNAc in the form of sulfation and methylation can change the total charge density, change in enthalpy (ΔH), change in entropy (ΔS) of glycans, which are specifically linked with alteration in various biological processes [13,16–18].

Additionally, the involvement of anomery and linkage of Gal and GalNAc in various biological activities are the main focus of the article. The literature data and experimental evaluations depict that the change in anomery and linkages cause the remarkable alteration in biological functioning. Infact, the alteration in physiological functions of glycans are specifically linked with the sequence and anomeric linkages of sugar molecules. The interaction property of *Artocarpus integrifolia* lectin with terminal αGal is the most common example in this context. *A. integrifolia* has significant binding potency for methylated α anomer (Galβ1-3GalNAcαMe) of T-antigen rather than its β anomer (Galβ1-3GalNAcβMe). This binding tendency is linked with ΔH and ΔS values calculated for both beta and alpha anomers of T-antigens. Similarly in ABH blood group system, blood group H antigen is converted into blood group A determinant by the terminal addition of GalNAc with specific anomeric linkage (α1-3). And blood group B antigen is formed by the terminal addition of Galα1-3 into H-antigen structure. So, we can say that the Gal and GalNAc with particular stereochemical features (anomery and linkage) are providing structural basis for wide range of cellular phenomena [13–18].

2. Role of sequence, linkage and anomery of Gal and GalNAc in various pathological activities

Carbohydrates carrying Gal and GalNAc residues are most common receptors for microbial infections like gonorrhoeae [19], sleeping sickness [20], meningitis [21], diarrhea [22], pneumoniae [23] and influenza [24]. Glycan–protein interaction is one of characteristic features of microbial adhesion. A microbial ligand exhibits different binding potency for the microbial isoreceptors due to alteration in stereochemical conformations. For example, *Propioni granulosum* (*P. granulosum*) is a normal human skin bacterium, while *Neisseria gonococcus* (*N. gonococcus*) is the gonorrheae pathogen. Both bacteria recognize the lactosylceramide motif (Gal β1-4 Glc1-1Cer), but have different specificity for isoreceptors. It is also perceived from experimental data that the *P. granulosum* has strong binding preference for glycolipids of lacto and neo-lacto series, but the *N. gonococcus* has weak binding potency for these series

[25]. Literature data has also proved that the terminal addition of Fuc into lactosylceramide motifs, inhibit the biding tendency of these bacteria. But if the Galα residue is introduced at position C-3, the poor adhesion property is observed.

Another example of microbial disorder is the sleeping sickness, which is regulated by protozoan parasite, *Trypanosoma brucei* in humans. This parasite contains Galα1-3Gal disaccharide domain on glycoprotein chain [20].

Streptococcus suis (*S. suis*) is another pathogen which has its involvement in development of neural disorders like stroke, neural tumor and meningitis. The cellular interaction between neural tissue and meningitis-causing bacteria (like *S. suis*) is mediated by the Gal containing oligosaccharide structure (as shown in Fig. 1). Galα1-4Gal is the most preferable disaccharide for potent binding interaction of *S. suis* with the host cells [21].

Shiga toxins having two major groups Stx1 (Shigella dysenteriae type 1) and Stx2, specially bind to galabiose portion of glycans. The literature study tells that the glycolipids deficient with galabiose sequences do not bind with shiga toxin. It is also observed that the majority of the glycolipids with internally positioned galabiose (Galα1-4Gal) are found inactive for shiga toxin binding. These intermolecular interactions are regulated between microbial and host body due to hydroxyl groups of sugar residues (Gal and GalNAc) [22–25].

Entamoeba histolitica (*E. histolitica*) is the causative agent of water born diseases. The favourable anomeric linkages for binding interaction of that pathogen are Galβ1-4 or Galβ1-3. The experimental study highlights that the removal of terminal Gal can affect the binding tendency of *E. histolitica*. Similarly, the terminal Gal with α1-4 linkage is found dynamic binding receptor for *Escherichia coli* (*E. coli*) interaction with human uroepithelial cells [26–28].

Additionally, the fabry disease is linked with the accumulation of glycolipids having Gal moiety with α anomery. The gathering of two such glycosphingolipids is detected in urine, blood plasma and other tissues of fabry's patient [29].

More advancement in cancer development has shown that the cancer markers like CA19-9 and CA125 behave as pointers for colorectal and ovarian cancers, respectively [30].

3. Lectins and glycan chemistry

Lectins, the *N*-linked glycoproteins are involved in several important physiological phenomena like cell death, immune system homeostasis, cancer phagocytosis and control of tumorigenesis. All the lectins, having same nature as that of Iris lectin can be discriminated on the basis of their interactions with detailed carbohydrate structures. For example, Peanut agglutinin (PNA) and Amaranthin specifically characterize the T-antigen disaccharide (Gal β1-3GalNAc) structure, while the Lima bean lectin (LBL) has strong binding potency for the blood group A trisaccharide unit. The strong binding specificity of Iris lectin for disaccharide motifs like GalNAcα1-3Gal and GalNAcα1-6Gal reflects the physiological significance of oligosaccharide chains as compared to monosaccharaides. These observations highlight that the lectins have an extensive carbohydrate binding domain, complementary to GalNAc residue. The literature study elucidates that the *N*-acetyl group (equatorial position) at the C-2 of GalNAc is the main functional group, which enhances the binding of GalNAc to the lectin. So, the GalNAc more effectively bind with the lectins as compared to Gal. Both the Forssman dissacharide and blood group A trisaccharide determinants are poor binders for Iris lectin and their interaction specificity for lectins proposes that the hydroxyl group at C-2 of penultimate Gal is the vital locus for the lectin binding. The poor binding tendency of Iris lectin with Forssman dissacharide is due to the steric hindrance of *N*-acetyl group present on the penultimate Gal residue [4].

Similarly, the leguminous plant Dolichos biflorus lectin (DBL) has significant binding specificity for GalNAc as compared to the Gal. It is perceived from reported data that the

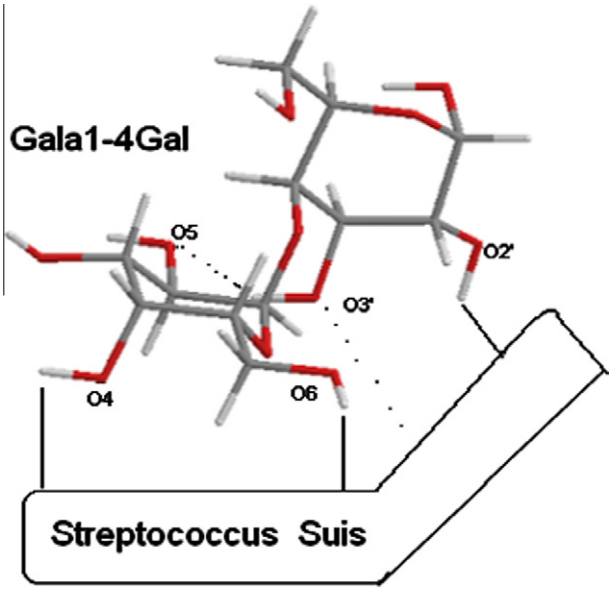

Figure 1 Intramolecular and intermolecular hydrogen bonding between the *Streptococcus suis* and disaccharide epitope.

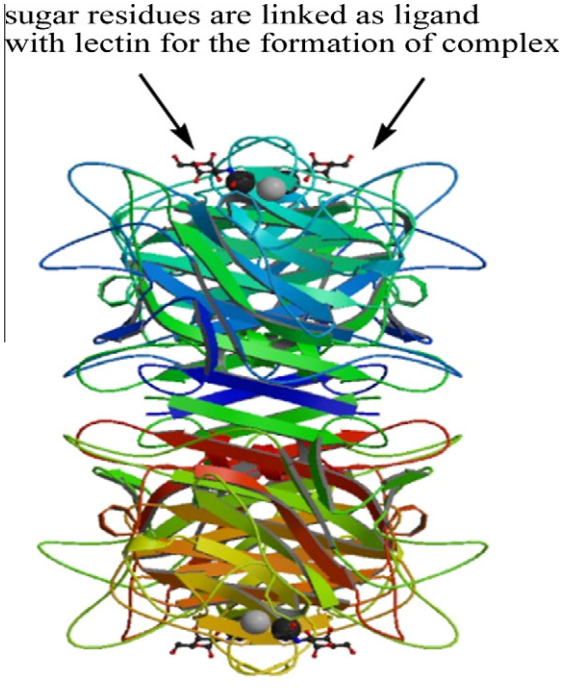

Figure 2 Complex of Dolichos Biflorus Seed Lectin with the Blood Group A trisaccharide [5–6].

complexation of blood group A and H variants with DBL is affected by blood group A trisaccharide epitope. The comparative study of DBL-Forssman complex and blood group A (trisaccharide)-DBL complex shows that the binding regions have low affinity for Gal as compared to GalNAc (Fig. 2). DBL has a powerful specificity of binding for GalNAc because the N-acetyl group gives compensation for the loss of aromatic stacking in DBL by creating the hydrogen bonding with the back chain amide group of Gly103 [5–6].

4. Functional efficacy of glyco-epitopes having terminal Gal and GalNAc

The study of glyco-epitopes is holding the vital position in numerous fields of life sciences and biotechnology. Glyco-epitopes are the valuable tools for regulating the wide range of physiological phenomena including cellular localization, pathogenic adhesion, embryonic development and the regulation of hormonal half lives in blood. The Lewis (Le) and ABO blood

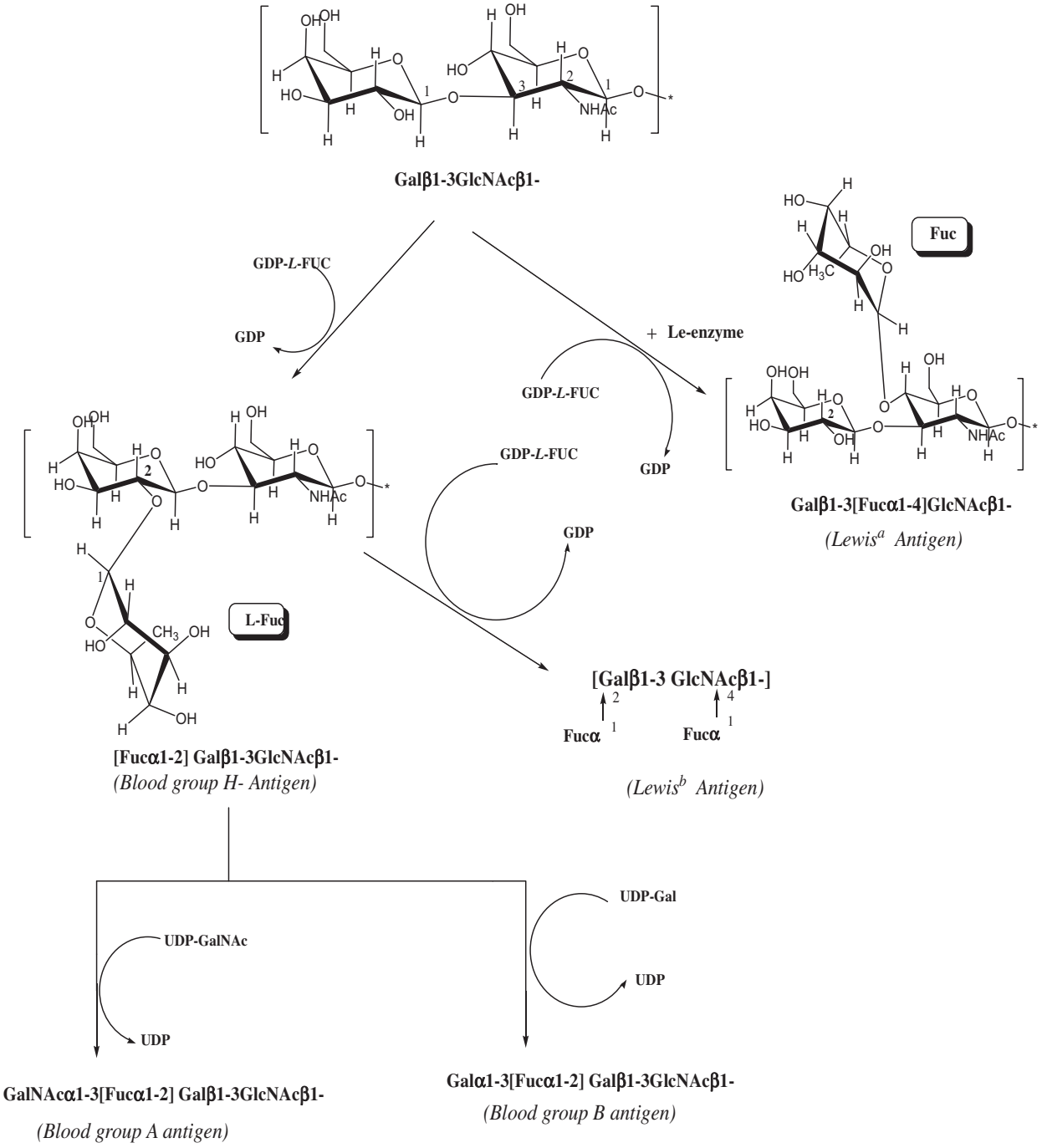

Figure 3 Glycosylation patterns of Galβ1-3GlcNAcβ1- to form the blood group A, B, H and Lewis blood group antigens.

Table 1 Glyco-epitopes and their involvement in various physiological activities.

Glycan ID/name	Epitope structure	Physiological context and references
EP0255/blood group A trisaccharide	GalNAc(α1-3)(Fuc(α1-2))Gal(β1-3)SGlcNAc(β1-)-R	Characterization of ABH blood group antigens into different mammalian tissues and recognition of normal and cancer cells [14–15,31]
EP0256/blood group A type 1	GalNAc(α1-3)(Fuc(α1-2))Gal(β1-3)GlcNAc(β1-)-R	Expression of Blood group A types in columnar cells of normal fetal mucosa [14–15,31]
EP0260/blood group A type 1 (difucosyl or A Le^b)	GalNAc(α1-3)(Fuc(α1-2))Gal(β1-3)(Fuc(α1-4))GlcNAc(β1-)-R	Localization of goblet cells of normal fetal mucosa [14–15]
EP0257/blood group A type 2	GalNAc(α1-3)(Fuc(α1-2))Gal(β1-4)GlcNAc(β1-)-R	Adenocarcinomas [14–15]
EP0261/blood group A type 2 (difucosyl)	GalNAc(α1-3)(Fuc(α1-2))Gal(β1-4)(Fuc(α1-3))GlcNAc(β1-)-R	Recognition of normal goblet cells and colon cancer [14–15]
EP0262/blood group B type 2	Gal(α1-3)(Fuc(α1-2))Gal(β1-4)GlcNAc(β1-)-R	Recognition of Fabry's disease [29]
EP0258/blood group A type 3	GalNAc(α1-3)(Fuc(α1-2))Gal(β1-3)GalNAc(α1-)-R	Detection of columnar cells of normal fetal mucosa, human cervical epidermal cancer, bladder and colon cancer [33]
EP0047/Asialo-GM1	GalNAc(α1-3)(Fuc(α1-2))Gal(β1-)-R OR Gal(β1-3) GalNAc(β1-4)Gal(β1-4)Glc(β1-1)Cer	Recognition of small cell lung carcinoma (SCLC) cell lines and antibody interactions [34–38]
EP0093/Dimeric Lewis x	Gal(β1-4)(Fuc(α1-3))GlcNAc(β1-3)Gal(β1-4)(Fuc(α1-3))GlcNAc(β1-)-R	Human cancer and fucosidosis [39–40]
EP0037/Forssman antigen	GalNAc(α1-3)GalNAc(β1-3)Gal(α1-4)Gal(β1-4)Glc(β1-1)Cer	Cestode serological cross-reactivity and interaction with embryonal carcinoma cells (ECC) [41–42]
EP0059/GD1	Gal(β1-3)GalNAc(β1-4)(Neu5Ac(α2-8)Neu5Ac(α2-3)) Gal(β1-4)Glc(β1-1)Cer	1. Localization of central and peripheral nervous system [11–12] 2. Prostate cancer marker [43]
EP0061/GD2	GalNAc(β1-4)(Neu5Ac(α2-8)Neu5Ac(α2-3))Gal(β1-4)Glc(β1-1)Cer	1. Targeting of lung carcinoma [44] 2. Human neuroectodermal tumor cells and gliomas [45]
H00218	Gal β (1-4)GlcNAc β (1-6))Gal β (1-3) GalNAc And Galβ1-3GlcNAcβ1-3GalNAc	1. Cystic fibrosis [46] 2. Bronchiectasis [47]

group antigens are biologically significant because these epitopes mediate the genetical and biochemical specificities on the red blood cells. Blood group H antigen is the precursor for blood group A, B and Leb antigens (Fig. 3). The blood group A determinants have the different epitopic domains of lacto-series. Blood group A type 1 structure is highly expressed in goblet and columnar cells of normal fetal mucosa, while the type 2 chains are accumulated in the human colon carcinomas. The glyco-epitopes of type 1 and 2 chains of blood group A differ only in their anomeric linkages at fucosylated Gal residues and this difference may provide the structural basis for their localization in normal and carcinomal cells. It can also be predicted from this example that the cellular characterization of normal and carcinomal tissues is specifically linked with the anomeric linkages of sugar residues [14,15,31–33]. Further elaboration about the implication of Gal and GalNAc containing epitopes in different biological processes is given in Table 1.

Similarly, the glycan study of fertilization process elucidates that the nature and sequence of the sugar residues are valuable tools for preventing the unintended pregnancy in mammals. Free-swimming sperms have significant adhesion specificity for *O*-linked glycoproteins (mZP1, mZP2 and mZP3) of zona pellucida. After binding interaction of sperms with the carbohydrate epitopes, sperms undergo the cellular exocytosis and acrosomal reaction which enable the sperms to penetrate the zona pellucid for fertilization. These male and female gametes interact with each other through Gal and GalNAc containing glycans and hence mediate the fertilization. Several parameters like the size, branching pattern and nature of the sugar residues are creating interruptions in sperm-egg interaction process. Two trisaccharides (Galβ1-4GlcNAcβ1-4GlcNAc) and (Galα1-3Galβ1-4GlcNAc)) having Galβ1-4 and Galα1-3 at their terminal ends are found important for inhibiting the sperm-egg adhesion with moderate affinity. While the addition of fucose residue in these two trisaccharides, produce the high affinity for the sperm-egg binding [48–49].

5. Effect of modifications (sulfation and methylation) in biological processes

Modifications like sulfation and methylation on Gal and GalNAc are linked with remarkable physiological functions including, regulation of cell growth, myelinisation, neuronal plasticity, pathogenic binding and characterization of cystic fibrosis and bronchitis [16,50–53]. e.g. The pathogenic adhesion of *Mycoplasma pneumonia* (*M. pneumonia*) occurs due to sulfate group at terminal Gal(β1-4). It is also observed that the removal of sulfate group affect the binding property of *M. pneumonia* with glycolipids. Similarly, the glycans having sulfate group at the C-3 and C-6 of Gal are involved in the characterization of different diseases like cystic fibrosis and bronchitis. SM3 and SM4 are sulfated glycolipids having their involvement in colon and hepatocellular carcinoma. The removal of sulfated SM4 has been documented with the inhibition of metastasis. Additionally, Sulfatide, a 3-O-sulfo galactosylceramide abundantly exists in myelin tissues and mediates the diverse range of physiological phenomena like neuronal plasticity, myelinisation, protein trafficking, signal transduction and morphogenesis. Methylation is the second type of modification on Gal and GalNAc, which has its specific physiological role in lectin binding or recognition process [23,46–53]. Physiological efficacy of these modifications and their association in various cellular phenomena are given below.

5.1. Physiological significance of sulfated Gal and GalNAc

Sulfated glycoconjugates occur in large variety of biological systems, in the form of glycoproteins, proteoglycans, glycolipids, and polysaccharides. The negative ionic potential of sulfate group is considered as a strong sticking force for wide range of glycans, which regulate vital physiological activities like cellular growth, adhesion, modification and communication in body.

In case of Gal, the attachment of sulfate group mostly occurs at C-3 and C-6, while in case of GalNAc this attachment occurs at C-4. The sulfoglycolipids like (3-sulfo-Lea) and (3-sulfo Lex) have strong ligand binding for both E- and L-selectins as compared to 3-sialylated derivatives of Lewis^a (Le^a) and Lewis^x(Le^x). The expression of 3-sulfo-Lewis^a epitope decreases with increasing the level of invasion of colonic carcinomas. While 3-SO_3-Le^a and 3-SO_3-Le^x determinants are also linked with the recognition of various carcinoma and nonmalignant epithelia [18,48–51].

The study of sulfated glycans shows that the sulfated Gal and GalNAc are engaged in recognition and progression of many carcinomas. Sulfated carbohydrate structures are also localized in the airway mucins, secreted by patients of bronchitis and cystic fibrosis [52–53]. Glycans in cystic fibrosis contain the Gal β1-3 moiety with sulfate group at the C-6. These glycans with the disaccharide (6Sulfated)Galβ1-3GalNAc, trisaccharide (6Sulfated)Galβ1-3GlcNAcβ1-3GalNAc, tetrasaccharide (6Sulfated)Galβ1-4GlcNAcβ1-3Galβ1-3GalNAc and pentasaccharide (6Sulfated)Galβ1-4GlcNAcβ1-3Galβ1-4GlcNAcβ1-3GalNAc structures are studied by Mawhinney et al., in 1987 [46]. But the fucosylated glycans in chronic bronchitis have sulfate moiety at the C-3 of Gal β1. Sulfated Gal in sulfatides is oligodendrocyte marker present in myelin sheet of adult brain. Sulfatides are also present in the form of seminolipids in the spermatogenic cells. The abnormities in paranordal junction, myelinisation process and prevention of neuronal degenerescence are also linked with the sulfatides. The literature data elaborates that the large decrease in sulfatide concentration mediates the Alzheimer disease with mild dementia [16,46–53].

Additionally, the sulfated glycans have prominent adhesion capacity for *M. pneumoniae*. This pathogen (*M. pneumoniae*) cannot distinguish between the 3-sulfogalactosylceramide and its 6-sulfo isoform. The terminal Gal(3SO4) β1- residues are the main receptors for adhesion of *M. pneumoniae* with glycolipids while in case of glycoproteins, the pathogenic binding takes place through NeuAcα2-3Galβ1-4GlcNAc motifs. These results corroborate that the sulfate group with at least Gal moiety in glycolipids is necessary for binding with the *M. pneumoniae* [23].

Additional detail about the physiological functions of sulfated glycans is given in Table 2.

5.2. Methylated Gal and GalNAc

Methylation is another type of sugar modification which influences the physical and chemical properties of glycans in macromolecular assemblies. Methylated glycans occur on lipids and proteins and are involved in various cellular activities like

Table 2 Active domains of sulfated glycoconjugates with their biological functions.

Antibody name	Antibody ID	Epitope name	Active domain	Biological functions and references
4A9E10	AN0386	SB1a	HSO3(-3)Gal(β1-3)GalNAc(β1-4)(HSO3(-3))Gal(β1-4)Glc(β1-1)Cer	Human hepatocellular carcinoma [49]
MIN/3/60	AN0226	3′-Sulfo Lewis x	HSO3(-3)Gal(β1-4)(Fuc(a1-3))GlcNAc-R OrHSO3(-3)Gal(β1-3)(Fuc(a1-4))GlcNAc-R	Leukocyte lectin interaction, Cystic fibrosis and bronchitis [50–53]
AIC31A2	AN0505	SM4s	HSO3(-3)Gal(β1-1)Cer	Lung cancer, myelination and spermatogenesis [16,54]
AIC31B3	AN0662	SM4s	HSO3(-3)Gal(β1-1)Cer	Lung cancer, myelination and spermatogenesis [16,54]
AG107	AN0544	6-Sulfo LacNAc	Gal(β1-4)(HSO3(-6))GlcNAc(β1-3)Gal(β1-4)Glc(β1-)-R	Human dendritic cell inflammation [55]
DD1	AN0523	6-Sulfo LacNAc	Gal(β1-4)(HSO3(-6))GlcNAc(β1-3)Gal(β1-4)Glc(β1-)-R	P-selectin interaction and human dendritic cell inflammation [55]
DD1	AN0523	6,6′-Sulfo LacNAc	(HSO3(-6))Gal(β1-4)(HSO3(-6))GlcNAc(β1-3)Gal(β1-4)Glc(β1-)-R	Human dendritic cell inflammation [55]
M-DC8	AN0522	6,6′-Sulfo LacNAc	HSO3(-6)Gal(β1-4)(HSO3(-6))GlcNAc(β1-3)Gal(β1-4)Glc(β1-)-R	P-selectin recognition marker and involve in dendritic cell inflammation [55]
F2 (3′-Sulfo Lewis a)	AN0597	3′-Sulfo Lewis a	HSO3(-3)Gal(β1-3)(Fuc(a1-4))GlcNAc-R	Selectin adhesion and antibody (91.9H) interaction [56]
49-D6	AN0135	SM3	HSO3(-3)Gal(β1-4)Glc(β1-1)Cer	L-selectin recognition marker [57]
AG273	AN0545	6-Sulfo Lewis x	Gal(β1-4)(Fuc(α1-3))(HSO3(-6))GlcNAc(β1-3)Gal(β1-)-R	E-, P- and L-selectin ligand binding and recognition of human lymph nodes [50,55–57]

cellular interaction, signaling and development. The simple example discussed to evaluate the implication of methylated is the recognition of *Artocarpus integrifolia* (*A. integrifolia*) lectin. *Artocarpus integrifolia* lectin has strong binding interactions for MeαGal and MeαGalNAc motifs (3). *A. integrifolia* has significant binding potency for methylated α anomer (Galβ1-3GalNAcαMe) of T-antigen rather than its β anomer (Galβ1-3GalNAcβMe). This binding tendency is linked with ΔH and ΔS values calculated for both beta and alpha anomers of T-antigens. Alpha anomer has strong binding interaction due to its high ΔH, which overshadow the ΔS influence. The association constant (Ka) values of disaccharides having αGal moiety are found lower than that calculated for the MeαGal. Literature study highlights that the removal of apolar methyl group in MeαGal cause the weakening of lectin binding with the resulting disaccharides (Galα1-3Gal and Galα1-3GalαMe). As the ΔG and ΔH for both disaccharide motifs (Galα1-3Gal and Galα1-3GalαMe) are same, but lower in case of MeαGal binding. Therefore it can be concluded that the lectin interaction takes place through terminal end of methylated glycans [13].

6. Databases annotation

Different glycan databases like Kegg database, Glycoepitope, Glycosuite, Glycome DB, Complex Carbohydrate Structural Database (CCSD), GlycoMaps, Glycobase and Glycoscience database are publicly present to evaluate the implications of sugar anomeric linkages in specific recognition activities serving as a tool for the therapy of cancer and other fatal diseases. These databases provide the information about glycan structures and their functional diversity, but are still limited about the structure-function relationship of sugar motifs.

Kegg: Kyoto Encyclopedia of Genes and Genomes database (http://www.genome.jp/kegg/) contains 10969 glycan entries some of which are methylated, phosphorylated and sulfated. Kegg database give information about structural ID, Composition, Mass, Structure, Class, biosynthetic pathway, orthology, enzyme details and KCF data of glycan chains. Each Kegg glycan entry starts with Alphabetical letter G.

Glycoepitope: Glycoepitope database (http://www.glyco.is.ritsumei.ac.jp/epitope/) has 146 glycoepitope entries. Each epitopic ID starts with English Capital letter EP. The information given against each entry contain data like Epitope ID, Sequence, Aliases, History, Molecular weight, Species, compositions and receptor explanation.

EURO Carb DB: EURO Carb database (www.eurocarbdb.org) consists of 13,457 unique glycan sequences of which 1 HPLC, 89 Mass Spectrometry, and 0 NMR analyses based structures are present.

Glycoscience: Glycoscience database (http://www.glycosciences.de/index.php) gives detail about structures, Theoretical Mass peaks, NMR Data, Taxonomy etc. This database contains 14857 different sugar structures having *O*-glycans (505), *N*-glycans (3415), and glycolipids (560).

GB: GlycoBase contains information about 350 glycans of which 117 glycans are human serum glycome. GlycoBase is a relational database having HPLC data of glycans (http://glycobase.ucd.ie, http://glycobase.univ-lille1.fr/).

CFG: Consortium for Functional Glycomics (www.functionalglycomics.org) database contains nearly 7500 entries. Each entry contains structural and chemical informations.

BCSDB: Bacterial Carbohydrate Structure Database (http://www.glyco.ac.ru/bcsdb3/) currently contains 9506 structures. Each entry contains BCSDB ID, Bibliography, (Sub) structure, Microorganism, NMR signals data.

Glycome DB: Glycome database (http://www.glycome-db.org/showMenu.action?major=database) gives information about Image of structure and their units.

7. Conclusion

Oligosaccharide structures are playing variety of roles in health and diseases. The significance of Gal and GalNAc containing epitopes in immunology, oncology and virology has been expressed in several experimental evaluations. However many questions are still present, such as the importance of anti-Gal antibody. This clearly highlights the need to amplify the current efforts to interpret the roles of Gal and GalNAc epitopes in normal and abnormal conditions in body. Additionally, the penultimate sugar residues attached with (specific linkages and anomery) Gal and GalNAc are also vitally important to provide physiological diversity by means of possible range of anomeric linkages. The current research article is an impetus for the scientists especially for young researchers to further interpret the memory capability of complex glycan structures, with the aim of designing the vital therapeutic elements for the cancer and various other diseases.

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